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Seasonal Variations of Tintinnids (Ciliophora Oligotrichida) in Narragansett Bay Rhode Island, U.S.A

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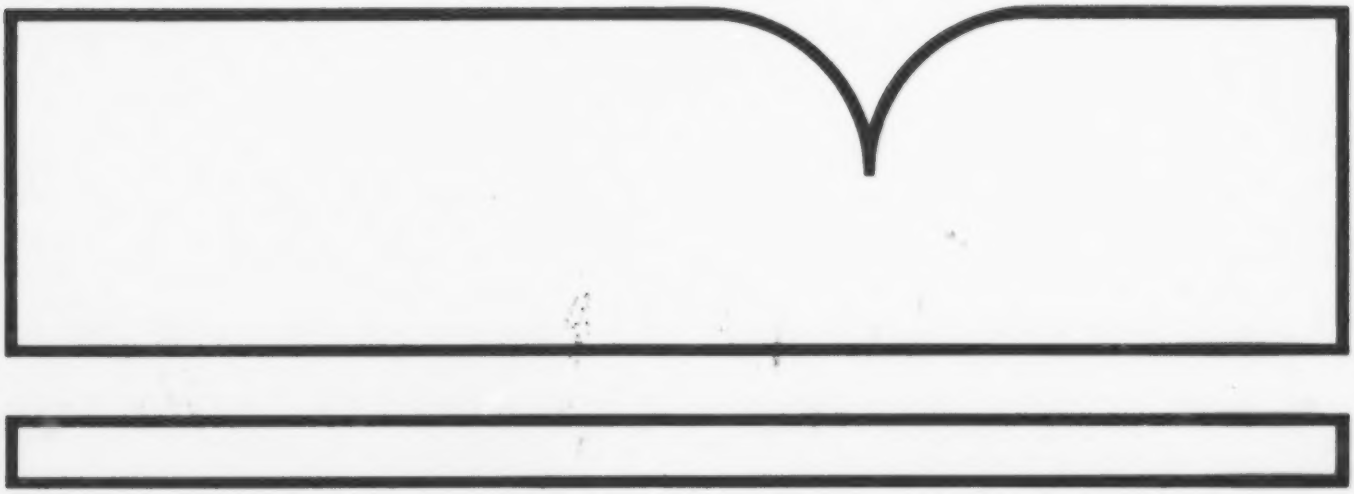

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16. ABSTRACT

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Seasonal variations of tintinnids (Ciliophora: Oligotrichida) in Narragansett Bay, Rhode Island, U.S.A.

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Abstract. Tintinnids exhibit a bimodal peak of abundance in Narragansett Bay, with a minimum in late spring and a lesser peak in late summer-early autumn, depending on location. Thirty-three species in eight genera were identified, with the fauna dominated by the genus *Tintinnopsis*. Tintinnid abundance was not obviously correlated with salinity, temperature, or nanoplankton chlorophyll concentration. Patterns of change in seasonal abundance can serve as a framework for posing additional questions of the role tintinnids play in marine food webs.

Introduction

The loricate ciliates, or tintinnids, are components of the micro- and nanoplankton which have usually been ignored by most plankton workers excepting taxonomists, despite their impact as grazers of nanoplankton flagellates and bacteria (Zeitschel, 1967), their rapid generation time (Heinbokel, 1978a), their role in nutrient regeneration (Johansen, 1976), and their potential as food for zooplankton (Zeitschel, 1967). Because of the relative sturdiness of the tintinnid lorica, taxonomic studies based on preserved material are plentiful. Even so, it is now clear that many taxa in the literature are questionable because of the great variation in morphology exhibited by many species (Baker and Phaff, 1976; Davis, 1978; Gold and Morales, 1975; Margalef and Duran, 1953). This problem, while serious, may not detract from the use of tintinnids as indicators of water mass types (Balech, 1972; Dowidar, 1974; Lindley, 1975).

Recently considerable information on the abundance and distribution of tintinnids has indicated their importance in oceanic (Beers and Stewart, 1971; Zeitschel, 1967) and coastal (Beers and Stewart, 1970; Hermosilla, 1972; Vitiello, 1964) waters. The ability to maintain tintinnids in culture (Gold, 1968, 1973; Heinbokel, 1978a) is leading to a quantification of the physiological and ecological aspects of the biology of this diverse ciliate group. Despite these advances, comparatively few data are available on the seasonal numerical changes of tintinnids in coastal waters. Yet such measurements are necessary adjuncts to physiological studies to assess the importance of tintinnids in coastal marine food webs.

During most of 1976 it was possible to study the tintinnid fauna of Narragansett Bay as part of a research program on the effects of oil toxicity on simulated marine ecosystems. This multi-investigator program is part of the MERL (Marine Environmental Research Laboratory) effort (Pilson *et al.*, 1979) and the experiments dealing with tintinnids will be reported in a subsequent

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publication.

The oceangraphic characteristics of Narragansett Bay are summarized in Hicks (1959) and Oviatt and Nixon (1975). Except for passing reference to the presence of tintinnids (Smayda, 1957, 1973) and a preliminary genus list (Pratt, 1959), the tintinnid fauna of Narragansett Bay is unknown, despite some 25 years of continuous plankton records and a considerable number of published work on the phyto- and zooplankton of this area. In nearby areas the tintinnids have only recently been investigated (Gold, 1975; Gold and Morales, 1975).

Materials and Methods

Approximately weekly samples were collected from four stations in Narragansett Bay from March through November 1976. The stations were part of a plankton research project conducted by Drs. E. and A. Durbin. The locations are shown in Figure 1. Durbin and Durbin (1980) present the results for stations 1, 2, and 5, while this report deals with stations 1, 3, 4, and 7. Station 1 is the same as that which Smayda (1957) and Furnas *et al.*, (1976) call 'Station 2'.

About 20 liters was collected at each station, consisting of equal amounts of surface, mid-depth, and bottom water. One liter of this was formalin-preserved and concentrated 100-fold by settling for 72 hours; then one ml. of the concen-

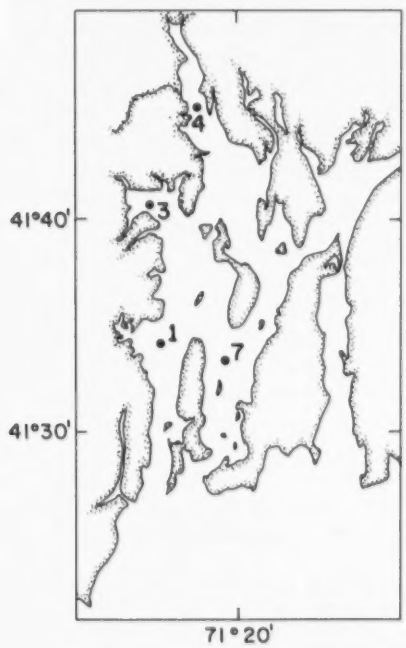

Fig. 1. Station Locations in Narragansett Bay.

trate, representing 100 ml., was examined and counted in a Sedgewick-Rafter cell at 200x and 400x. The counting procedure was repeated twice more. The data in Figures 3 and 4 were kindly made available by Drs. A. and E. Durbin, and the methods involved in its collection are found in Durbin and Durbin (1980).

Results

The seasonal variation in total tintinnids is shown in Figure 2. Similar patterns occur at all four stations: a peak in abundance in late May or early June, a precipitous decline in late June, another lesser peak in late summer, with a more gradual decline in October. The vernal period is subject to considerable fluctuation, particularly at station 1 and 7, both of which are more strongly influenced by open coastal conditions. Tintinnid populations in the late summer are comparatively stable at stations 1 and 7, but less so at stations 3 and 4 which are, respectively, a semi-enclosed cove and the mouth of the Providence River. Although the first population peak coincides in time at all stations, the second does not: at stations 1 and 7 it is evident in mid-July; at station 4 in mid-August. At station 3, the second peak is delayed until late September. The maximum populations ($1.04 \cdot 10^4 \cdot {}^{-1}$ at station 3; $1.39 \cdot 10^4 \cdot {}^{-1}$ at station 7) are among the highest numbers recorded for natural populations of tintinnids.

Figure 3 shows seasonal variation in temperature and salinity for the four stations. The progression of temperature is typical for temperate estuaries and coastal waters, with a steady rise through spring, a mid-summer peak, and a gradual decline in autumn. Stations 1 and 7, more subject to the effects of coastal and offshore waters, are slightly cooler and more regular in the rate of change. Durbin and Durbin (1980) found scant evidence of thermal stratification, except on few and temporary occasions of calm weather coupled with high insolation.

The seasonal changes in salinity are rather small, rarely being less than 28 °/oo or more than 32°/oo. Stations 3 and 4, more influenced by fresh water input, are slightly lower in salinity but apparently not subject to rapid fluctuations (note scale changes for salinity on right ordinate of Figure 3).

Variations in phytoplankton standing stocks as measured by chlorophyyl-a during 1976 are described in Durbin and Durbin (1980) for Narragansett Bay. The data presented in Figure 4 include only the nanoplankton (less than 20 μ) fraction. Although a mid-summer maximum with considerably lower standing stocks in early spring and late autumn are the dominant characteristics of the nanoplankton, considerable fluctuations are common. Ten-fold differences are seen, both among the four stations on the same date (especially in mid-summer) and between successive dates at the same location (*e.g.* station 1 in late June).

The 33 tintinnid taxa identified from station 1 and their abundance throughout the sampling period are presented in Table I. Only eight genera were seen, with the genus *Tintinnopsis* being overwhelmingly dominant in terms of total taxa (21) and abundance (usually over 90% of total tintinnids). In the spring period *T. parva* and *T. tubulosoides* were numerically dominant in the plankton, with *T. rapa* and *Helicostomella subulata* also abundant. During the late spring maximum *T. acuminata* and *T. minuta* became dominant, while *T. tubulosoides* disappeared,

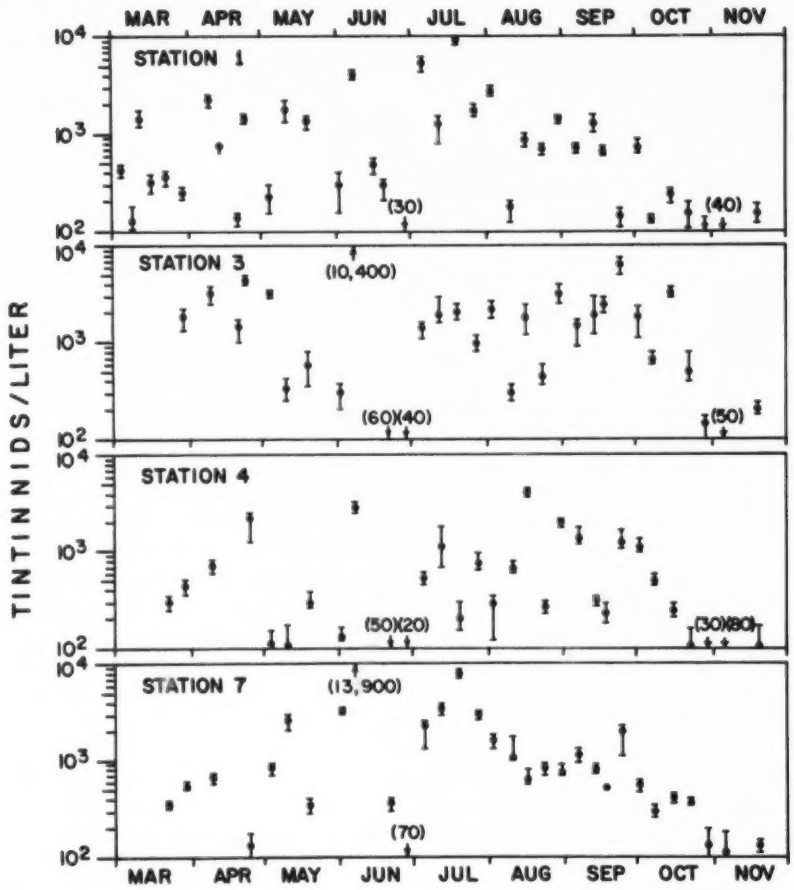

Fig. 2. Abundance of Total Tintinnids at Stations 1, 3, 4, and 7 in March - November, 1976. Data points show mean and range of triplicate counts.

and *T. parva* and *T. rapa* declined considerably. *H. subulata* declined but persisted throughout the summer until the early autumn. No single species dominated the population during the autumn period when total tintinnid abundance was rather low. *H. subulata, T. sufflata,* and *T. ventricosoides* were sporadically important.

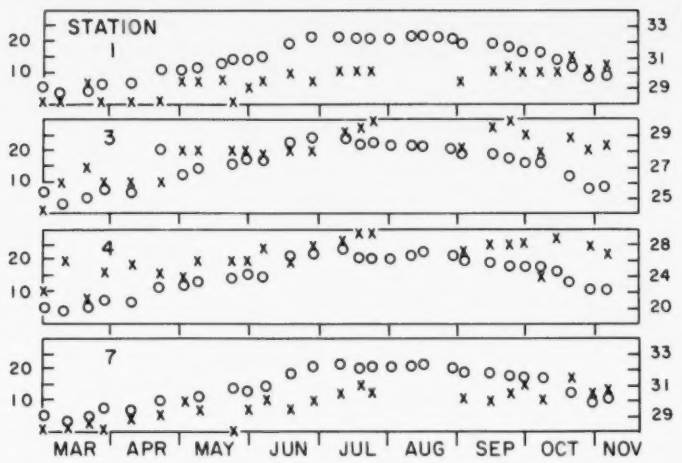

Fig. 3. Seasonal Variation of Temperature and Salinity at Stations 1, 3, 4, and 7. (0 = temperature; x = surface salinity) Left ordinate is centigrade degrees; right ordinate is per mille salinity. Note scale changes in right ordinate.

A few taxa were ephemerally important during one season and absent or negligible at other times. These included *T. baltica, T. tubulosa,* and *T. cf. undella* in spring; *Stenosemella oliva, S. ventricosa, T. kofoidii, and Tintinnus sp.* in the summer; and *Favella ehrenbergii* and *Tintinnopsis sufflata* in the early autumn. The remainder of the taxa in Table I were of minor quantitative importance.

Comparable patterns were also evident at the remaining three stations with a few exceptions. *Tintinnidium fluviatile,* a species preferring reduced salinity environments, was more abundant at station 4, the mouth of the Providence River. *Tintinnopsis minuta,* which dominated the mid-summer population at station 1, was even more abundant at station 3, but less so at station 7. The genera *Stenosemella* and *Tintinnus* were more abundant at station 7, which receives more net inflow of coastal water than station 1. Three additional species were seen at other stations which do not appear in Table I. *Tintinnopsis karajacensis, T. levigata,* and *T. lobiancoi.* These were rarely present and never in any abundance. The taxonomic status of *T. karajacensis* and *T. lobiancoi* is questionable (Halme and Lukkarinen, 1960; Bakker and Phaff, 1976), and they are perhaps not to be distinguished as separate taxa.

Discussion

Since the seasonal changes in salinity are rather small, and since most estuarine and coastal tintinnids presumably tolerate modest changes in salinity, there is no apparent relationship between tintinnids and salinity variation, except for abundance changes of a few species, noted above, at stations where river or open

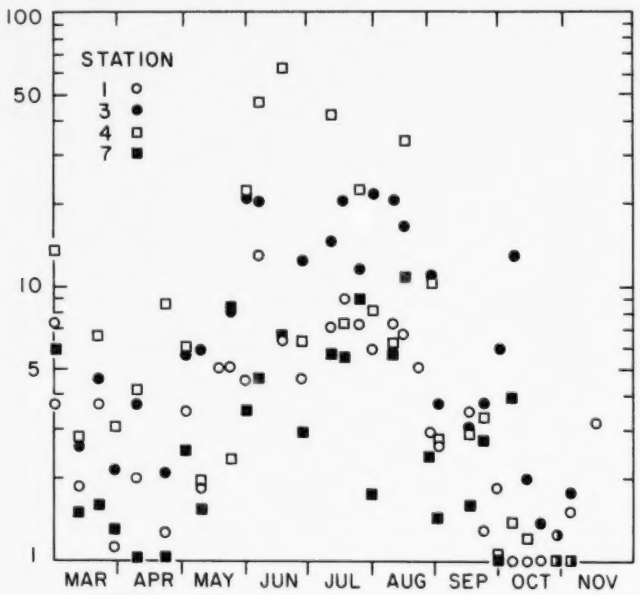

Fig. 4. Seasonal Variation of Nanoplankton (less than 20μm) Chlorophyll at Stations 1. 3.4. and 7. (Ordinate: log scale in $\mu g \cdot l^{-1}$ chlorophyll-a).

influence is more pronounced (stations 4 and 7 respectively). However, there is a notable absence of data on responses of tintinnids to salinity fluctuations, either *in situ* or *in vitro,* as perusal of Kinne's (1971) review volume shows. Gillbricht (1955) noted a tendency for *Tintinnopsis* sp. to accumulate at density discontinuities, and Kuwahara *et al.* (1975) found *Favella tarakaensis* more abundant near haloclines. The latter authors also found no correlation between tintinnid abundance and *in situ* chlorinity in the absence of water stratification. This appears to be the case in Narragansett Bay as well, where the mixing normally prevents formation of stratification throughout most of the year with the exception of the upper bay in mid-summer (Oviatt and Nixon, 1975).

The maximum populations of tintinnids as well as number of taxa occurred during late spring and late summer-early autumn when the temperatures were around 20°C. It would be erroneous to imply a direct cause and effect here since specific thermal preferences, food supply, predator abundance, and other biological influences must all have their effect on the intrinsic rate of tintinnid growth. In nearby open coastal water, Gold and Morales (1975) found the maximum number of taxa in autumn, while in oceanic waters Zeitschel (1967) found a biomodal peak in seasonal abundance in the cool Irminger current and a less pronounced seasonal variation in the warmer waters to the south. In the White Sea, Burkovsky (1976) found maximum populations in summer and minima in winter.

Table 1. Species occurrence of tintinnids at Station 1, March-November, 1976 (individuals per liter: 1 = 10-50; 2 = 51-100; 3 = 101-500; 4 = 501-1000; 5 = 1001-5000; 6 = 5001-10,000). Divided into half months.

	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
Favella ehrenbergii							3 1	1	
sp.						1			
Helicostomella fusiformis			1						
subulata		1	3 5	2 1	1 3	3 2	3 3	1	
Metacylis annulifera						1 2	1 1		
Parafavella sp					1				
Stenosemella oliva					3	1 1		1 1	
steinii	1						1		
ventricosa					1 4	1			
Tintinnidium fluviatile		1		1		1 2	1 1	2	1
Tintinnopsis acuminata				1 2	2 5	4 2	1 1	1	
baltica		3 1		2 2	1 3	1 1	1 3	1 1	1 1
beroidea		1 2			2				
dadayi					1		1		
fimbriata									1
kofoidii				1	4 2	3 2	1 1	1 1	
minuta			1	4 2	6 3	3 2	1 2	2 2	
nucula					2				
parva	1 2	3 4	3 3	2 3	1 1	3 3	2 1	1 1	1 1
parvula		1 1	1						
platensis						1	1		
rapa	1	3 3	1 1	1 1	1 2	3 2	2 1	1 1	1 1
sufflata					2	1 1	4 3	2 2	1
tubulosa	1 3	3 1						1	1
tubulosoides	1 3	5 3	1					1 1	
cf. *undella*		2 3						1	
urnula	1								1 1
vasculum	1	1	1		1	1	1		1
ventricosoides		1	1	1 1	3 2		1 1	3 1	1 1
spp.		1 1			1	3			
Tintinnus pectinis						1			
sp.					4	1 2	1		
TOTAL	3 3	5 5	4 5	5 3	6 6	5 4	4 5	4 3	3 3

In direct contrast, Vitiello (1964) found tintinnids most numerous in winter in the Bay of Algiers, at a time when the Atlantic Ocean influence is greatest. The most direct effects of temperature are more likely in the area of annual faunal changes, biogeography, and morphology (*e.g.* Gold and Morales, 1975) than in short term population changes.

Tintinnid abundances greater than 10^4 per liter are rarely reported. Partly this is due to a basic lack of information from coastal areas. The bulk of tintinnid literature deals with taxonomic problems (of which there are many), distribution in time and space, and, more recently, the role of tintinnids in marine food webs. Much of the quantitative data available are of the 'rare-common-abundant'. sort. On a per liter basis Zenkevitch (1963) has reported $5 \cdot 10^4$ for the Azov sea, and Vitiello (1964) $3 \cdot 10^4$ for the Bay of Algiers. Oceanic populations are considerably

lower. For example, barely over 10^2 in the Philippine Sea (Taniguchi, 1977) and in the North Atlantic as well (Zeitschel, 1967). Thus, while the populations for Narragansett Bay are not phenomenal, they unquestionably are a significant part of the microzooplankton.

The faunal composition of tintinnids can be compared with that of the nearby New York Bight region (Gold and Morales, 1975), where eleven genera and 34 species were found. Three genera found in the New York Bight but not in Narragansett Bay are *Ptychocylis, Coxliella,* and *Parundella.* Since these are typical open coastal forms, their absence from the estuarine Bay is not surprising. Species found in Narragansett Bay but not the New York Bight are *Tintinnopsis fimbriata, T. nucula, T. parvula, T. sufflata, Tinntinnus pectinis,* and *Helicostomella fusiformis.* The latter is sometimes synonymized with *H. subulata.*

A complication in comparing these faunal lists is the indistinct boundary among species, particularly in *Tintinnopsis.* Bakker and Phaff (1976) for example, suggest integradation between *T. beroidea* and *T. minuta, parvula,* and *rapa;* likewise between *T. lobiancoi* and *T. tubulosa, karajacensis, tubulosoides,* and several others. Clearly the taxonomic status of many species is subject to question until comparative morphological studies of field populations coupled with culture studies can be made. For the present, one of the most conservative features seems to be the width or oral diameter of the lorica (Gold and Morales, 1975; Bakker and Phaff, 1976).

The reasons for fluctuations in tintinnid populations are little known but food supply is certainly important. Spittler (1973) and Heinbokel (1978b) have shown that the maximum size of particles grazed by some tintinnids is 40-45% of the oral diameter, while the minimum size is not clearly known. Tintinnids grow well on diets of 'naked' flagellates (Gold, 1971; Heinbokel, 1978a), which make up most of the nanoplankton chlorophyll in summer in Narragansett Bay. But the abundance of tintinnids follow only in a general way the changes in nanoplankton chlorophyll (*cf.* Figures 2 and 4). This seems to support Chester's (1978) report that ciliate abundance (including tintinnids) were related to chlorophyll concentrations in offshore waters, but less so near shore. But in contrast, Johansen (1976) found a positive relationship between tintinnids and nanoplankton, and concluded that tintinnids could control nanoplankton abundance. In this regard, the observation by Prakash (1963) that the tintinnid *Favella* is a major cause of the disappearance of the toxic dinoflagellate *Gonyaulax tamarensis* is especially intriguing.

A major constituent of the summer tintinnid population is *Tintinnopsis minuta,* which presumably feeds on particules with a maximum size of about 4-7 μm (oral diameter of 11-15 μm). That size range excludes many of the photosynthetic cells in the less than 20 μm fraction in Narragansett Bay, which tend to be larger than 10 μm, such as *Olisthodiscus luteus, Skeletonema costatum,* and various prasinophytes and dinoflagellates (Durbin *et al.,* 1975; and personal observations). If food supply is of major importance in influencing tintinnid abundance, and since nanoplankton chlorophyll does not correlate particularly

well with tintinnid abundance, what might other explanations be for the poor corrlation? Obvious but not exclusive alternatives are the structure of the sampling program and the utilization of non-photosynthetic particles as food.

Heinbokel (1978a) has shown that tintinnid doubling times can be as low as 12 hours. This approximates the doubling time for nanoplankton in Narragansett Bay as well (Durbin *et al.*, 1975), but theoretically nanoplankton can grow faster than this (Eppley, 1972). If short term changes in the intrinsic growth rate of either tintinnids or photosynthetic nanoplankton are significant in terms of subsequent tintinnid population changes, the data set based on approximately one week interval sampling may have missed critical events in the plankton. The fact that large changes occurred from week-to-week is in itself indicative that this is a problem.

Particulate organic carbon (POC) may be ingested by tintinnids as food, and considerable POC is present in Narragansett Bay (Sieburth, 1968). This seston is composed of organic debris and aggregated bacterial colonies along with inorganic particles. It is probable that at least a portion of this material is ingested as food, with non-digestible particles being incorporated into the loricae of the arenaceous tintinnids.

Free-living bacteria and non-photosynthetic flagellates are also a possible source of food. Sieburth (1967) and Sieburth *et al.*, (1977) have shown, not only bacterial concentrations of 10^4-$10^5 \cdot ml^{-1}$, but also that diurnal growth patterns of bacteria are quite pronounced, adding further significance to the problem of sampling intervals in measurement of tintinnid abundance patterns. Bacteria are apparently not a major constituent of the diet for larger tintinnids (Gold, 1968; Laval-Peuto *et al.*, 1979) but could be so for such small species as *Tintinnopsis minuta*.

Non-photosynthetic choanoflagellates and chrysomonads are abundant in the summer plankton of Narragansett Bay (personal observations) but have not been quantitatively studied. They can easily exceed $10^5 \cdot ^{-1}$ in coastal waters (Throndsen, 1969). At least one tintinnid can utilize choanoflagellates, both as a food source and as a source of particulate materials in lorica construction (Gold, 1968).

The effect to which predation influences tintinnid populations is completely unknown. Euphausiids are major consumers of tintinnids, based on gut analysis (Ponomareva *et al.*, 1963), but copepods, tunicates, and fish larvae may also consume considerable numbers (Zeitschel, 1967). In laboratory studies, ciliates were acceptable food for copepods (Berk *et al.*, 1977; Heinle *et al.*, 1977) although no published work has specifically evaluated tintinnids as food. The dominant summer copepods in Narragansett Bay in 1976 were *Acartia* spp. (Durbin and Durbin, 1980) which may be too small to be effective predators on most tintinnids. However, larger copepods, invertebrate larvae, and fish, particularly the menhaden *Brevoortia tyrannus* (Durbin and Durbin, 1975) are abundant in Narragansett Bay in summer, and are potentially effective influences on tintinnid populations.

While the abundance of tintinnids in Narragansett Bay is considerable, the ex-

tent to which their grazing effects their food supply, and in turn the extent of their availability as food for predators, are still undefined. In light of their recently recognized importance in marine food webs, basic information on seasonal abundance of tintinnids can best be used as a framework to pose additional questions.

Acknowledgments

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